

# **Impact Burial Prediction for Mine Breaching Using IMPACT35**

Peter C. Chu

Department of Oceanography Naval Postgraduate School Monterey, CA 93943

tel: (831) 656-3688 fax: (831) 656-3686 email: [pcchu@nps.edu](mailto:pcchu@nps.edu)

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## **LONG-TERM GOALS**

The long-term goal is to predict operational mine (e.g., Rokan, Manta, Bowen, and Korean) maneuver in water column and burial in sediment for shallow water (water depth around 40 – 60 ft).

## **OBJECTIVES**

- To establish mine impact burial data set with operational mine shapes for impact burial prediction
- To update IMPACT35 for operational mine shapes such as Manta, Rockan, etc.
- To implement a new technique (pseudo-cylinder parameterization scheme) into IMPACT35
- To provide the experimental data with operational mine shapes to the mine burial prediction community
- To deliver IMPACT35 to the mine burial prediction community
- To integrate the NPS mine impact burial prediction model into the Commander Naval Meteorological and Oceanographic Command (CNMOC) mine warfare program for operational use

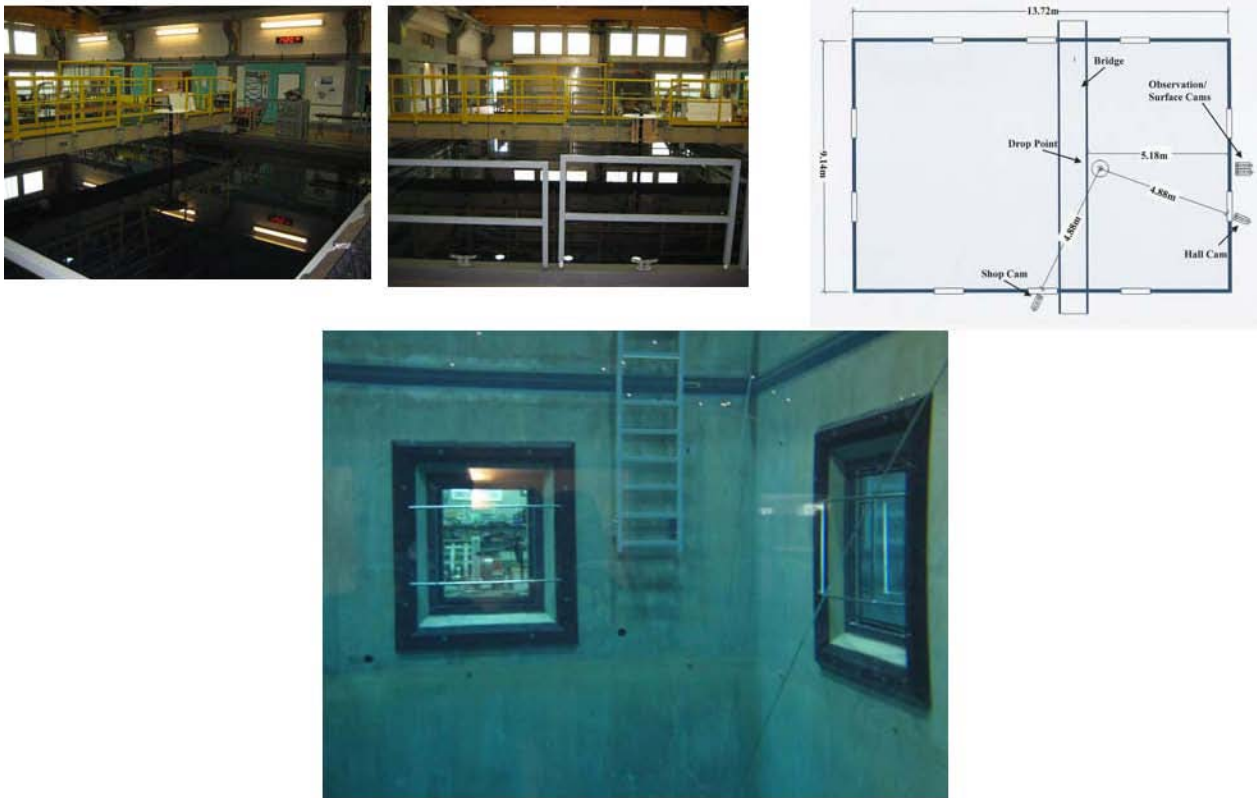
## **APPROACHES AND RESULTS**

Several approaches were taken to develop IMPACT35 for operational mine shapes.

### **(A) NPS Mine Drop Experiment with Operational Mine Shapes**

We conducted a new mine drop experiment (NPS-MIDEX-II) with four operational mine shapes at the Monterey Bay Aquarium Research Institute (MBARI) Unmanned Underwater Vehicle Test Tank (Figure 1). Enclosed inside a large building, this 10 m×15 m×10 m tank was filled with “standard sea water.” This water was maintained by an ozone filtration system, with no impurities save the remnants of blue dye placed into the tank several weeks prior to the experiment. The faint

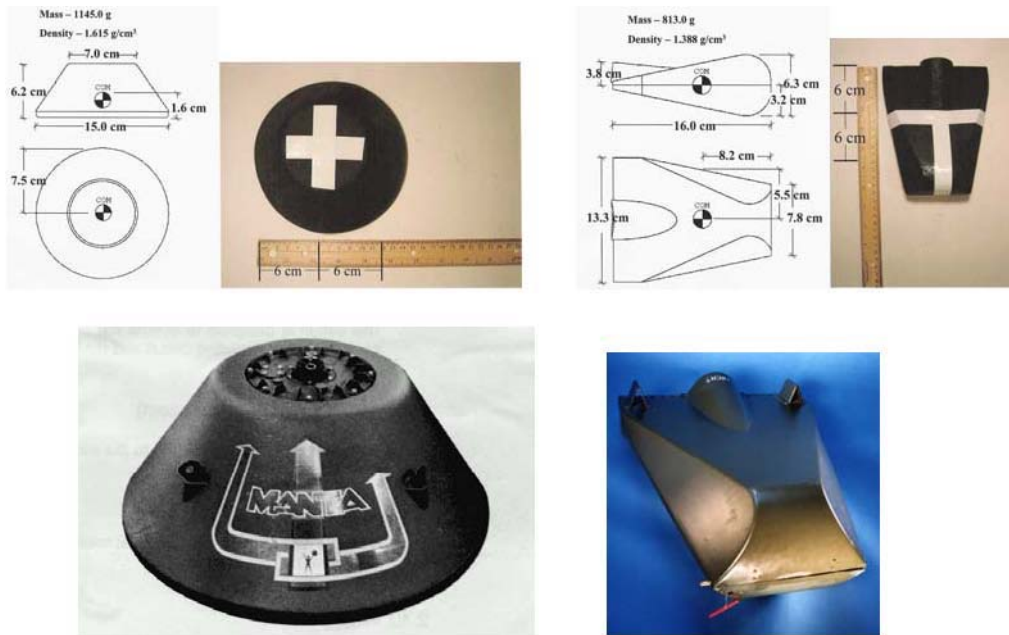
blue coloration had no effect on the shape trajectories, but it did add some difficulty illuminating the tank. Hence the video data quality was somewhat degraded. A sliding bridge, on which the slanted board was mounted, spanned the width of the tank. Figure 1 describes the measurements of the tank and placement of the drop zone, cameras, and lighting.



***Figure 1. (a) MBARI Test Tank Facility (structure above water is moveable bridge), (b) top view of MIDEX-II setup, (c) side view of the tank.***

Mine shapes were selected based upon current and future operational relevance. A collection of four mine-like polyester resin test shapes were used: sphere, a semi-hemispherical “Gumdrop” shape, a scale model of the Manta bottom mine, and a scale model of the Rockan bottom mine (Table 1). The Sphere was selected to serve as a “calibration” shape because its shape symmetry and equal weight distribution about its three axes. The Gumdrop was similar in shape to but higher in density than the Sphere. The Gumdrop was selected to act as a kind of “traditional” shape of bottom sea-mines, though no mine was specifically represented (Figure 2).

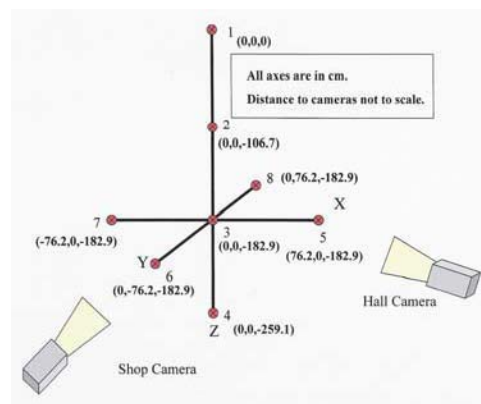
NPS-MIDEX-II was conducted by two experimenters via handheld walkie-talkies. One stayed on or near the moveable bridge with the shapes. The other was stationed with the high-speed cameras (Figure 3) and computer and served to coordinate the filming and retrieval of the subsurface data. For each individual drop, the experimenter below confirmed the readiness of the cameras and prepared the computer to save the appropriate film file. When this was confirmed, he signaled the one above, who turned on the high-wattage tank lighting, selected the designated shape, and held the shape against the slanted board in the “ready” position.



**Figure 2. Manta- and Rockan-shaped model mines.**

**Table 1. Mass and density of model mines.**

Model	Description	Mass	Density
Model 1	Generic Sphere Shape	1692.0 g	1.335 g/cm <sup>3</sup>
Model 2	Gumdrop Hemispherical Shape	2815.0 g	1.722 g/cm <sup>3</sup>
Model 3	Manta Bottom Influence Mine Shape	1145.0 g	1.615 g/cm <sup>3</sup>
Model 4	Rockan Bottom Influence Mine Shape	813.0 g	1.388 g/cm <sup>3</sup>



**Figure 3. Underwater cameras.**

Each shape was dropped just above the surface of the water and filmed with a pair of high-speed cameras as the shape fell through the water column. Each trajectory was then converted to an array of Cartesian coordinates and analyzed with software specifically designed to work with the high-speed

cameras. Data retrieval was accomplished by converting the digital video imagery from each drop into an array of x-y-z coordinate data (Figure 4).



*Figure 4. Examples of high speed film frames.*

## (B) Data Analysis

Commercially available 3-D motion analysis software, MAXTRAQ, was the primary tool utilized to perform this function. Initially, the software was calibrated into the 3-D coordinate reference system utilizing the pairs of calibration images obtained in the initial phase of the experiment. Following calibration, both camera views were time synced and analyzed to determine the actual position of the shape in the x-y-z coordinate field. Frame-by-frame analysis was performed with the software for each view by manually identifying and input. Table-2 shows the sample data for Manta mine shape. These data are ready for the mine burial prediction community to use.

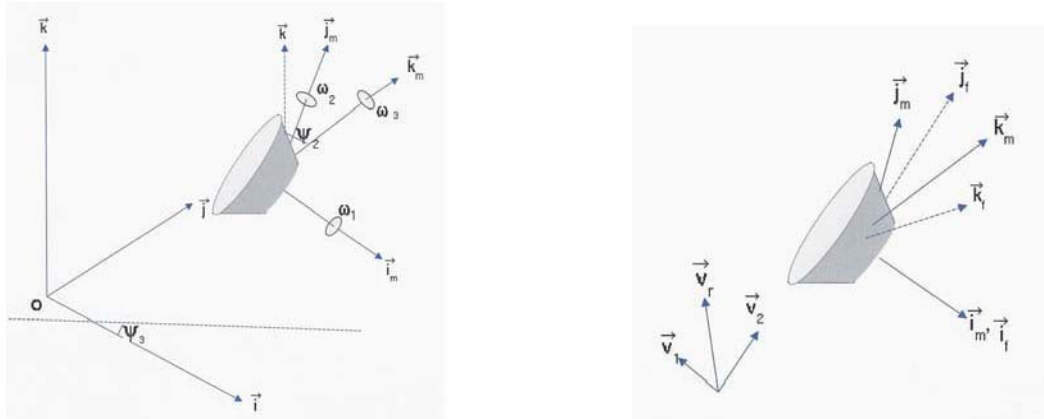
*Table 2. Examples of data for Manta Mines*

Manta	v1=										
5	3.116										
time	pos(x)	pos(y)	pos(z)	el	az	x1	y1	z1	x2	y2	z2
0	0	0	0	-0.7165	-1.8868	0.2273	0.6953	-0.6371	-0.2273	-0.6953	0.6371
0.016	-0.748	1.1373	-3.1868	0.2542	-1.856	-0.3519	2.4886	-2.821	-1.1442	-0.2139	-3.5526
0.032	-0.5424	-0.1067	-9.9725	-0.5003	-1.7608	-0.3707	0.7862	-10.4696	-0.7141	-0.9996	-9.4754
0.048	-1.0062	0.1588	-14.9747	-1.2983	-1.9182	-0.8714	0.531	-16.3917	-1.141	-0.2135	-13.5576
0.064	-0.6907	-0.2062	-20.2648	-1.3224	-2.0538	-0.5257	0.1086	-21.6666	-0.8558	-0.521	-18.8631
0.08	-0.6085	-0.0342	-25.3783	-1.1793	2.3993	-0.2535	-0.3598	-26.5455	-0.9635	0.2915	-24.2111
0.096	-0.1589	-0.3256	-29.6856	-1.1973	-2.3535	0.0811	-0.0842	-30.5543	-0.399	-0.5669	-28.8169
0.112	-0.4386	-0.9452	-34.8807	-1.0897	-2.9573	0.0192	-0.8599	-35.7727	-0.8964	-1.0305	-33.9886
0.128	-0.7294	-1.849	-39.2502	-1.0669	2.6172	-0.3806	-2.0507	-39.9809	-1.0781	-1.6472	-38.5195
0.144	-0.1735	-2.7783	-42.744	-1.1728	1.7718	-0.111	-3.085	-43.4884	-0.236	-2.4716	-41.9996
...	...	...	...	...	...	...	...	...	...	...	...

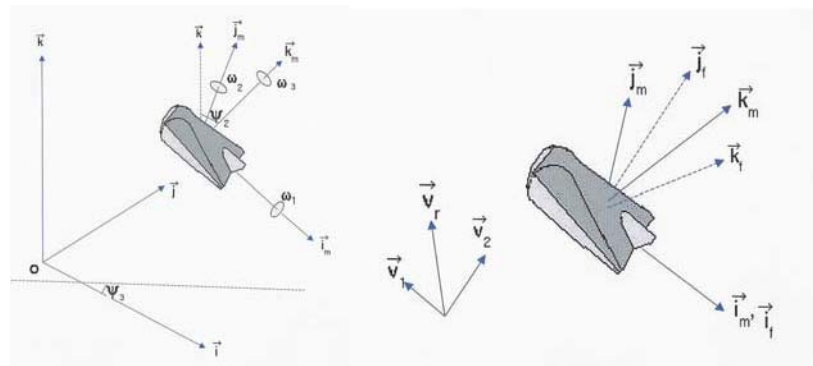
## (C) Core-Dynamics

The updated IMPACT35 not only predicts the effects of mine size, density, center of gravity (CG), and center of buoyancy (CB), but also the effect of the shape. Shape is a significant issue. The most important issue is to determine the hydrodynamic (drag and lift) force and torque for non-cylindrical mines. There is no existing formula for calculating the drag and lift forces and torques for non-cylindrical objects. We transformed the non-cylindrical mine into “equivalent” cylindrical mine. Here, the nonlinear instability and model sensitivity were studied. Within the correct physics, the model has

capability to handle chaotic behavior. In the new version of IMPACT35, multi-coordinate systems are designed for Manta mines (Figure 5) and Rockan mines (Figure 6).



**Figure 5. Multi-coordinate systems for Manta mines.**



**Figure 6. Multi-coordinate systems for Rockan mines.**

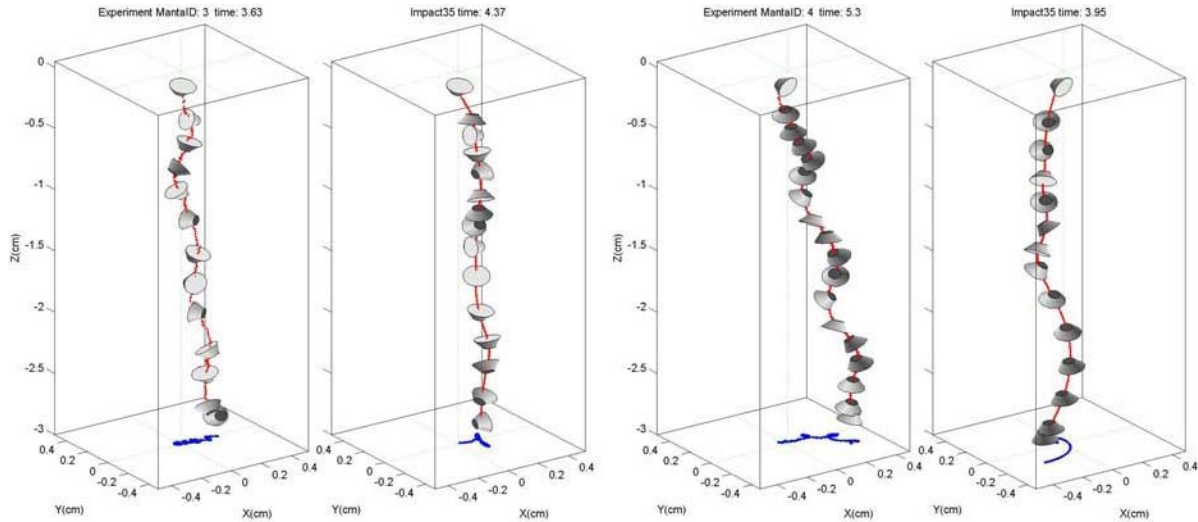
The distinction between IMPACT35-cylinder and IMPACT35-Manta (or IMPACT-Rockan, ...) is on the hydrodynamic coefficients (drag and lift coefficients). There is no existing formulae for calculating drag and lift coefficients for the operational mine shapes (Manta, Rockan, ...). We use the inverse method to obtain these coefficients for operational mine shapes using the NPSMIDEX-II data.

(D) Publications of four papers on NPS-MIDEX-II (operational mine shapes) and IMPACT35 modeling results in Journal of Applied Mechanics, IEEE Journal of Oceanic Engineering, and Advances in Fluid Mechanics.

(E) Presentations of three papers at the Seventh International Symposium on Technology and Mine Problems, NPS, Monterey, California, May 1-4, 2006, and the International Symposium on Advances in Fluid Mechanics, Skiathos, Greece, May 8-10, 2006.

## RESULTS

- (1) We use the updated IMPACT35 to predict the Manta and Rockan mines' trajectories in the water column and to compare with the NPS-MIDEX-II data (Figure 7). As evident, IMPACT35 has capability to predict the maneuvering of operational mines in the water column.



***Figure 7. Model-data comparison of Manta mines maneuvering in water column.***

- (2) We establish detailed data set for mine maneuvering in the water column (with operational mine shapes). The data went through thorough quality control procedures and ready to deliver to Mine Burial Prediction community.
- (3) Inverse method is proved an efficient method to determine the drag and lift coefficients of Manta and Rockan mines from the experimental data.

## WORK COMPLETED

- Mine drop experiment with operational mine shapes (Manta, Rocka, Gunlop, and Sphere) was conducted. Huge data about mine maneuvering were obtained.
- The experiment data went through thorough quality control procedures and stored as ascii files. It is very easy to be used by the community.
- The new scheme for computing drag and lift coefficients for operational mine shapes has been implemented and verified using the NPS-MIDEX-II data.
- Four coordinate transform method was developed and evaluated. This method is the core of the hydrodynamic part of IMPACT35 for operational mine shapes. The theoretical part of the method will be submitted to the Journal of Applied Mechanics.

- The comparison between IMPACT35 and NPS-MIDEX-II has been conducted.
- The new results were published in peer-reviewed journals such as IEEE Journal of Oceanic Engineering and Journal of Applied Mechanics.
- The new results were presented in the Seventh International Symposium on Technology and Mine Problems, NPS, Monterey, California, May 1-4, 2006, and the International Symposium on Advances in Fluid Mechanics, Skiathos, Greece, May 8-10, 2006.

## **IMPACT/APPLICATIONS**

- The dynamic system (nonlinear equations) for the mine movement has the potential impact on the nonlinear dynamics. The hydrodynamics of mine impact in water column can be applied to a general scientific problem of the fluid-rigid body interaction including stability and chaotic motion.
- The non-cylinder parameterization scheme will impact the scientific and Naval mine warfare communities on the movement of non-cylindrical mines in the water column.
- The inverse method for determining drag and lift coefficients for operational mine shapes from the mine drop experiments can be applied to general mechanical and aerodynamical engineering problems.

## **RELATED PROJECTS**

This project is related to the ONR Expert System program. The results obtained from this project are the basic materials for building the Expert System for mine burial prediction.

## **THESES DIRECTED:**

Charles Allen, Mine drop experiments with operational mine shapes, MS in Meteorology and Oceanography, March 2006.

## **TRANSITIONS**

- The results obtained from this project are transferred to the Naval Oceanographic Office, COMINWARCOM, and the ONR Mine Impact Burial Prediction group such as the mine expert system and mine scour and liquifaction groups.
- IMPACT35 with air-water-sediment columns was transferred to the IBPM community such as to Drs. Alan Brandt and Sarah Rennie at the APL Lab in the John Hopkins University, Drs. Phil Valent, Andrei Abelev, and Paul Elmor at the Naval Research Laboratory.
- IMPACT35 was used for development of the Expert System for Mine Impact Burial at the Applied Physics Laboratory of the John Hopkins University and the Monte Carlo system at the Naval Research Laboratory.
- The model mines for the NPS-MIDEX were shipped to Drs. Phil Valent, Andrei Abelev NRL-Stennis Space Center for subsequent mine burial experiments.

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